use of biofuels, such as biodiesel and bioethanol, to reduce the country's dependence on imported petroleum products.

» *Waste-to-Energy:* Waste-to-energy technologies convert municipal solid waste into electricity or heat. These facilities not only provide renewable energy, but also help in waste management and reducing landfill waste.

India is making significant strides in harnessing a variety of renewable energy sources to meet its growing energy demands sustainably. The country's renewable energy sector continues to evolve and expand, with a focus on solar, wind, biomass, and hydropower as the primary contributors to the renewable energy mix. As technology and infrastructure improve, India is also exploring other renewable sources like geothermal, ocean energy, and biofuels to further diversify its renewable energy portfolio.

Government policies for renewable energy integration

India has been actively pursuing a sustainable and low-carbon energy transition; renewable energy plays a vital role in achieving this ambitious goal. To promote the widespread adoption and seamless integration of renewable energy into the national energy mix, the Indian government has implemented a series of comprehensive policies, incentives, and initiatives. These measures aim to create an enabling environment for renewable energy development, attract investments, and address the challenges associated with clean energy integration.

» *National Solar Mission (NSM)*: Launched in 2010, the National Solar Mission is one of India's flagship programs aimed at promoting solar energy deployment across the country. The mission set an ambitious target of achieving 100GW of solar capacity by 2022, which was later increased to 450GW by 2030. The government provides various incentives and financial support mechanisms such as subsidies, tax benefits, and viability gap funding to encourage solar power projects. The NSM also promotes research and development in solar technology to drive down costs and improve efficiency.

» *Wind Energy Policy and Auctions:* India has a long history of wind energy development, and the government has been actively supporting the sector through policy frameworks and competitive auctions. Wind power projects benefit from feed-in tariffs, generation-based incentives, and accelerated depreciation. India aims to build 140 gigawatts (GW) of wind capacity by 2030 and it continues to explore opportunities for offshore wind projects to harness the country's vast wind potential.

» *National Offshore Wind Energy Policy:* Recognizing the untapped potential of offshore wind resources along its vast coastline, the Government introduced the National Offshore Wind Energy Policy in 2015. The policy framework aims to facilitate the development of offshore wind projects by identifying suitable zones and streamlining regulatory procedures. The policy also offers financial incentives to attract investors and technology developers to explore this promising sector.

» *Renewable Purchase Obligation (RPO):* The RPO is a regulatory mechanism that mandates electricity distribution companies, open-access consumers, and captive power plants to procure a certain percentage of their energy from renewable sources. RPOs vary across states and are periodically revised to encourage utilities and consumers to invest in renewable energy projects and reduce their carbon footprint.

» *Green Energy Corridors:* To facilitate the integration of renewable energy into the national grid, the government launched the Green Energy Corridors project. This initiative focuses on the development of dedicated transmission corridors to evacuate power from renewable energy-rich regions to demand centers. The project aims to address the grid congestion challenges and improve the efficiency of power transmission from renewable sources.

» *Research and development (R&D) support:* The Indian government promotes research and development in renewable energy technologies through various funding mechanisms and collaborations with research institutions and industry partners.

R&D support aims to accelerate innovation, improve the performance of renewable technologies, and foster indigenous manufacturing capabilities.

» *International cooperation and agreements:* India actively engages in international partnerships and agreements to access expertise, technology, and funding for renewable energy projects. Initiatives like the International Solar Alliance facilitate cooperation among solar-rich countries to promote solar energy deployment globally.

Indian government has demonstrated a strong commitment to supporting renewable energy integration through a mix of policy incentives, financial support, regulatory mechanisms, and international collaborations. These measures have helped India emerge as a global leader in renewable energy adoption. As the country continues to strive for a sustainable energy future, government support remains crucial for furthering the growth of clean and renewable energy sources in the country.

Challenges

Renewable energy integration in India, while promising for its potential to drive sustainable development and combat climate change, faces several challenges that must be addressed to ensure a smooth transition to a greener energy future. These challenges stem from various technical, financial, regulatory, and social factors. Understanding and mitigating these challenges are essential for achieving India's ambitious renewable energy targets and maximizing the benefits of clean energy sources. The key challenges are listed below.

» *Intermittency and variability:* Renewable energy sources, such as solar and wind, are inherently intermittent and variable in their generation patterns. The availability of sunlight and wind fluctuates throughout the day and across seasons, leading to fluctuations in energy output. This poses challenges for grid stability and requires advanced grid management, energy storage solutions, and flexible demand-response mechanisms to balance supply and demand.

» *Grid infrastructure and integration:* Integrating a significant amount of renewable energy into the existing grid infrastructure can be challenging. The grid must be equipped to handle bi-directional power flows and manage intermittent injections of renewable energy. Upgrading and modernizing the grid to accommodate distributed energy resources, smart grid technologies, and advanced grid management systems is essential for efficient renewable energy integration.

» *Energy storage and grid balancing:* The lack of efficient and cost-effective energy storage technologies remains a major hurdle for renewable energy integration in India. While advancements in battery storage are progressing, widespread deployment of large-scale storage systems is still limited. The availability of reliable energy storage solutions is crucial to store excess energy during peak generation and release it during periods of low generation, ensuring a continuous and stable power supply.

» *Land acquisition and resource allocation:* Establishing renewable energy projects often requires substantial land resources, which can lead to conflicts over-land use and create social and environmental challenges. Identifying suitable locations for renewable energy installations, while balancing environmental concerns and local community interests, is a critical task that requires careful planning and stakeholder engagement.

» *Financing and investment:* The high upfront costs associated with renewable energy projects can be a deterrent for investors, especially in a developing economy like India. While the cost of renewable technologies has decreased over the years, securing affordable and long-term financing remains a challenge. Encouraging private sector investment, providing favorable policies, and promoting innovative financing mechanisms are essential to accelerate renewable energy deployment.

» *Policy and regulatory framework:* A stable and supportive policy environment is crucial for attracting investments and encouraging renewable energy adoption. Frequent policy changes, uncertainties in regulations, and inconsistent implementation can hinder the growth of the renewable energy sector. A clear and long-term policy framework that includes incentives, feed-in tariffs, and market-based mechanisms is essential for fostering investor confidence.

» *Grid congestion and curtailment:* In some regions, grid congestion can limit the absorption of renewable energy, leading to curtailment of excess generation. This can result in the wastage of clean energy resources and financial losses for project developers. Addressing grid congestion through grid expansion, dynamic grid management, and market-based mechanisms is necessary to optimize the utilization of renewable energy.

» *Technological and skill challenges:* Adopting and deploying advanced renewable energy technologies may require specialized skills and knowledge. Developing a skilled workforce that can design, operate, and maintain renewable energy systems is crucial to ensure the efficient functioning of these projects.

India's journey towards a sustainable future through renewable energy integration faces multiple challenges. These challenges, ranging from technical complexities to policy and financing issues, need to be systematically addressed through a collaborative effort involving the government, private sector, research institutions, and civil society. Overcoming these hurdles will enable India to harness its vast renewable energy potential and transition towards a cleaner, greener, and more resilient energy system.

Success Factors

The successful integration of renewable energy in India can be attributed to several key factors that have contributed to the growth and adoption of clean energy sources. These success factors have played a crucial role in fostering a favourable environment for renewable energy integration and have accelerated the country's transition towards a more sustainable energy future. The key success factors are:

- *Ambitious renewable energy targets:* India's commitment to ambitious renewable energy targets has been a driving force behind the rapid growth of clean energy installations. The government's clear and ambitious goals, such as the National Solar Mission and the wind energy targets, have provided a roadmap for investors and developers, instilling confidence in the renewable energy sector.
- *Supportive policy environment:* India has implemented a range of policies and regulatory frameworks to support renewable energy integration. Incentives such as subsidies, tax benefits, and feed-in tariffs have encouraged investments and project development in the renewable energy sector. Policy stability and consistency have been crucial in attracting domestic and foreign investments and driving growth.
- *Feed-in tariffs and competitive bidding:* The introduction of feed-in tariffs and competitive bidding mechanisms for renewable energy projects has facilitated a competitive market, ensuring that renewable energy tariffs are cost-competitive with conventional sources. Competitive bidding has driven down the cost of renewable energy projects, making them more attractive to utilities and consumers.
- *Grid infrastructure development:* Investments in grid infrastructure and expansion have been critical in enabling the smooth integration of renewable energy into the existing power grid. The establishment of green energy corridors and smart grid technologies has enhanced grid stability, enabled efficient power transmission, and accommodated the variable nature of renewable energy generation.
- *Private sector participation:* The active participation of the private sector, both domestic and international, has been instrumental in driving renewable energy growth in India. Private players have brought in capital, technology, and expertise, contributing to the rapid expansion of renewable energy projects across the country.
- *Funding:* India has leveraged international collaborations, to access funding, technology, and expertise from solar-rich nations. This has accelerated the deployment of solar projects and enhanced India's position as a global leader in renewable energy adoption.
- *Public awareness and community engagement:* Increasing public awareness of the benefits of renewable energy and engaging local communities in project development have been crucial in gaining social acceptance and support for renewable energy projects. Community-based renewable energy initiatives have proven successful in fostering a sense of ownership and inclusiveness.
- *Energy storage and innovation:* Advancements in energy storage technologies have helped address the intermittency of renewable energy sources, making them more reliable and suitable for grid integration. Innovation in energy storage solutions has played a pivotal role in enhancing the overall effectiveness of renewable energy systems.

The success of renewable energy integration in India can be attributed to a combination of these aspects. Continued efforts in these areas, along with a commitment to sustainable development, will be crucial in furthering India's renewable energy journey and achieving its long-term clean energy goals.

Impact on economy

Renewable energy has a profound impact on the economy, offering a wide range of benefits that positively influence various sectors and aspects of economic development. Here are some of the key impacts of renewable energy on the economy—

- *Job creation*: The renewable energy sector creates a significant number of jobs across various stages of the value chain, from manufacturing and installation to maintenance and operation. These jobs span a wide range of skill levels, providing opportunities for both skilled and unskilled labor. The growth of the renewable energy industry contributes to reducing unemployment and stimulating economic activity in regions where renewable projects are established.
- *Investment and economic growth*: The development of renewable energy infrastructure attracts substantial investments from both domestic and international sources. These investments spur economic growth, as funds are channeled into project development, research and development, and the manufacturing of renewable energy technologies. Additionally, the construction and operation of renewable energy projects contribute to local and regional economic development.
- *Energy security and import reduction*: By relying on indigenous renewable energy resources, countries can enhance their energy security and

reduce dependence on imported fossil fuels. This shift in energy sourcing helps stabilize energy prices, improve balance of trade, and reduce vulnerability to international energy market fluctuations, thereby strengthening the national economy.

- *Environmental benefits and cost savings*: Renewable energy sources produce little to no greenhouse gas emissions, leading to cleaner air and reduced environmental pollution. As a result, countries can save on healthcare costs associated with air pollution-related illnesses. Moreover, the adoption of renewable energy can mitigate climate change impacts and the associated economic costs, such as damage from extreme weather events.
- *Technological innovation and industrial growth*: Investments in renewable energy stimulate research and development efforts to improve technologies, increase efficiency, and reduce costs. This technological innovation spills over into other industries, leading to advancements in manufacturing, energy storage, and grid management technologies. As a result, a dynamic and competitive renewable energy sector fosters industrial growth and enhances overall economic competitiveness.
- *Rural development and social benefits*: Renewable energy projects, such as small-scale solar and biomass installations, are often deployed in rural areas with limited access to conventional grid electricity. These projects improve energy access and quality of life for rural communities, encouraging local economic development and creating income-generating opportunities.
- *Cost stability and price competitiveness*: Renewable energy technologies benefit from declining costs, making them increasingly price competitive with fossil fuels. As the cost of renewable energy continues to decrease, consumers and businesses can benefit from more stable and predictable electricity prices, reducing the risk of price fluctuations and enhancing overall economic stability.
- *Sustainable development and corporate social responsibility:* The adoption of renewable energy aligns with sustainable development goals and enhances a country's image in the global arena. Companies that invest in renewable energy demonstrate environmental responsibility and social consciousness, enhancing their corporate social responsibility profile and appealing to socially conscious consumers.

The impact of renewable energy on the economy is multifaceted and far-reaching. It generates employment, attracts investments, strengthens energy security, fosters technological innovation, and contributes to sustainable development and environmental preservation. As countries continue to transition towards renewable energy, the positive economic impacts are expected to grow, further solidifying the role of renewables in shaping a more sustainable and prosperous future.

Conclusion

Renewable energy has emerged as a transformative force in shaping economies worldwide. In the context of India, the integration of renewable energy sources has ushered in a new era of sustainable development, fostering numerous positive impacts on various economic sectors and facets of growth. The remarkable strides made by India in harnessing renewable energy are evident through ambitious initiatives. These policies, coupled with a supportive regulatory environment, have encouraged investments and facilitated the deployment of clean energy infrastructure. Renewable energy's transformative impact is not confined to urban areas alone; it extends its reach to rural communities—improving energy access and promoting rural development. Perhaps one of the most significant contributions of renewable energy to the Indian economy is job creation. This not only contributes to economic upliftment, but also underscores the importance of inclusive growth and social development.

The sector has become a major employer, providing opportunities for a diverse workforce across manufacturing, installation, and maintenance activities. The influx of investments further bolsters economic growth, while reducing reliance on imported fossil fuels enhances energy security and positively impacts the balance of trade. The environmental benefits of renewable energy are equally compelling, leading to cleaner air, mitigating climate change impacts, and reducing healthcare costs of pollution-related illnesses. Additionally, the technological advancements spurred by the renewable energy sector have a ripple effect, benefiting other industries and enhancing India's overall competitiveness in the global market. In embracing renewable energy, India embraces a brighter, cleaner, and more sustainable future. The journey towards a renewable-powered economy is an inspiring testament to India's determination to build a better tomorrow for its people and the world. EF

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SOLAR–WIND HYBRID RENEWABLE ENERGY SYSTEM

World's major electricity requirements are met via expensive, fast depleting fossil fuels. In addition, this energy generation is accompanied by the release of greenhouse gases. This calls for increasing our reliance on renewable energy solutions, particularly in rural areas. The present article, authored by **Dhanush Binu** and **Dr Jyotirmay Banerjee**, makes us aware about the potentials of a solar–wind hybrid renewable energy system. The system, apart from supplying uninterrupted power supply, is environmentally benign.

Introduction

In India which has the highest population worldwide, 65.5% of the total population resides in rural areas with inconsistent access to electricity. Majority of the world's electricity is presently produced using expensive, quickly depleting fossil fuels like coal, oil, and natural gas, accompanied by production of greenhouse gases (GHGs). Thus, there is an emphasis towards increasing the share of renewable energy for electricity generation, particularly in rural areas. This is because in most part of rural India one of the renewable sources such as solar or wind or hydro is found in abundance.

Currently among renewable sources, wind and photovoltaic (PV) systems are deployed on a wider scale. These independent systems are however unable to produce a continuous source of energy as they are seasonal. Wind stand-alone systems cannot meet the load demands because of fluctuations in wind speed throughout the year and solar PV systems are not able to provide reliable power during nighttime. Hybrid renewable energy system (HRES) is an integration of two or more renewable energy sources to produce a high-quality power supply that is independent on the national grid. Hybrid systems, incorporating two or more renewable energy sources, coupled with an energy storage system and an algorithm to operate the system has the potential to be a promising technology for power generation, especially in rural areas.

Among all renewable energy sources, the integration of solar and wind energy sources is considered most effective due to their complementary nature, hence, providing a reliable and cost-effective option for rural electrification. A key advantage of this system is that it can deliver continuous power throughout the day without interruption with the incorporation of an energy storage device which stores excess energy and uses it in case there is no power generation from the both the units.

Solar and Wind Energy Potential in India

The total potential of renewable energy in India stood at 1,097,465 megawatt (MW) (as of 2020). Out of this, solar power potential is leading with 748,990 MW while the wind power potential is 302,251 MW at 100 m hub height (IEA 2021). The distribution of India's potential for renewable energy is shown in Figure 1.

Solar potential

India is endowed with vast solar energy which is equivalent to about 5000 trillion kilowatt hour (kWh) per year. Most parts of India receive 200–250 sunny days/year and can provide a daily average of 4–7 kWh/m^2/day which is almost equivalent to the average daily consumption per household in India (10 kWh/household) (MNRE 2021). Solar PV power can be harnessed effectively, hence, providing huge scalability in India. Solar energy provides us with the ability to harness power in a decentralized manner which is off-grid and hence independent households can have their own electricity-producing system. Off-grid decentralized and low-temperature applications are viewed as

beneficial for rural electrification in India.

With the premise that 3% of India's waste land area will be covered by solar panels, the National Institute of Solar Energy (NISE) estimated the country's solar potential to be at 748 GW. The Government of India's National Solar Mission (NSM) aims to develop 100 GW of grid-connected solar PV power plants by 2022. India has surpassed Italy to take fifth place globally in solar PV installation. As shown in Figure 2,

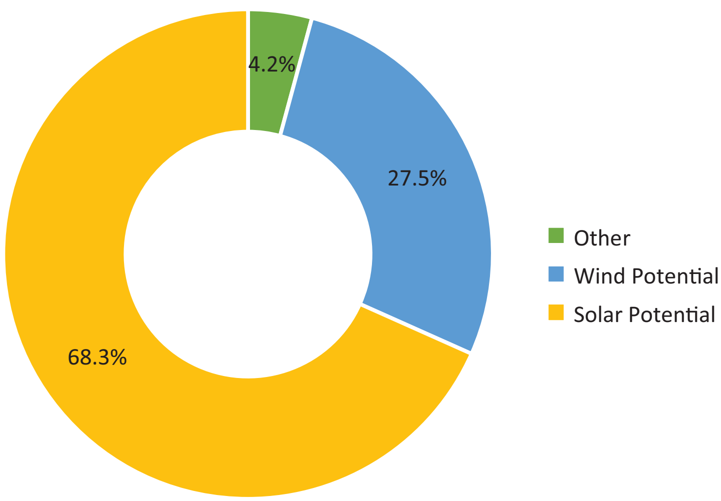

Figure 1: India's estimated potential of renewable energy as of 2020

the solar power capacity has expanded more than six times in five years, from 6800 MW in 2016 to 40100 MW in 2021 (MNRE 2021).

Wind Potential

India ranked fourth in global position in wind energy capacity with a total of 39,250 MW (as of 2020). India has the second-highest wind capacity in Asia and generated roughly 60.149 billion units between 2020 and 2021. India has the third (1500 MW: Muppandal Wind Farm in Tamil Nadu) and fourth (1064 MW: Jaisalmer Wind Park in Rajasthan) largest onshore wind farms in the world. To evaluate the country's wind resources, the Indian Government, through the National Institute of Wind Energy (NIWE), has installed more than 800 wind-monitoring stations. Wind potential maps have been created at altitudes of 50, 80, 100, and 120 m above ground level. India has a capacity for 695,500 MW at 120 m above the ground and 302,000 MW at 100 m, according to a recent evaluation.

Seven states in India have shown wind potential of more than 44,000 MW at 100 m and 74,900 MW at 120 m. Out of these seven states Gujarat has highest wind potential with 84,430 MW at 100 m and 142,560 MW at 120 m, followed by Rajasthan with 18,770 MW at 100 m and 127,750 MW at 120 m (MNRE 2021). The wind energy industry currently accounts for the majority of India's total renewable energy capacity, or 41.5%, with an installed capacity of 39,248 MW. Evolution of installed wind capacity in India from 2016 is shown in Figure 3.

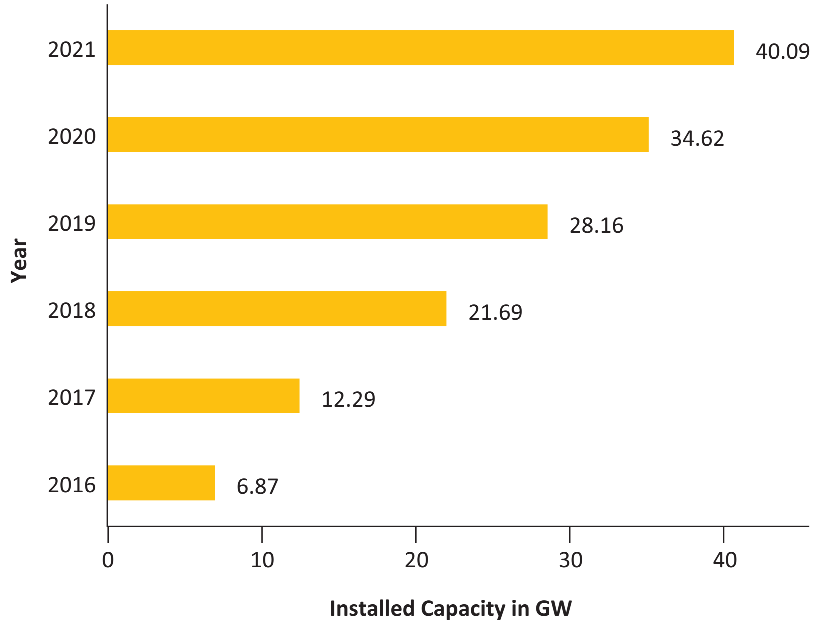

Figure 2: Evolution of installed solar capacity

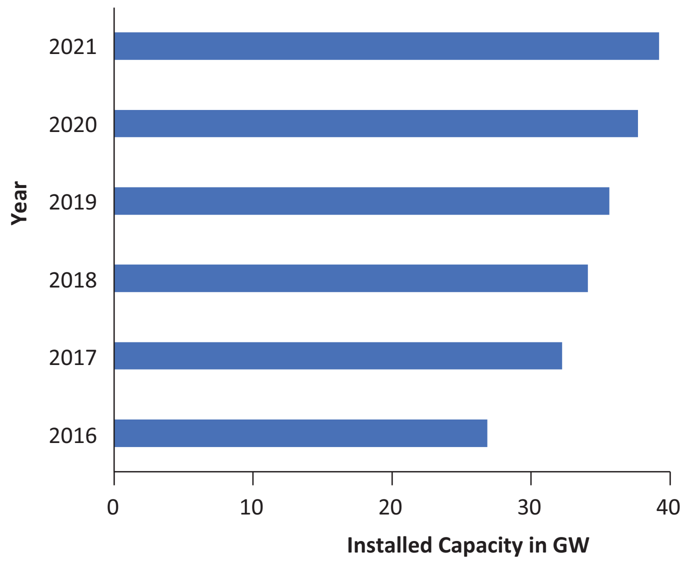

Figure 3: Evolution of installed wind capacity

Case Study

To understand the feasibility of hybrid systems, a case study was conducted for a rural location in India. A solar–wind hybrid system was designed and simulated using HOMER software to meet the power demand of three households with uninterrupted power supply throughout the day. At first, the wind speed and solar irradiation data for the selected site was collected and assessed to evaluate the monthly average wind speed and solar irradiation. The power needs of a rural household were calculated based on daily usage to estimate the load demand of the system. From the above two sets of data, the system components were sized. Once sizing was completed, the next step involved modelling of the hybrid system and simulations to predict the influence of parameters on the system performance towards possible improvements in the system design. Figure 4 summarizes the whole process flow.

The bock diagram of the solar–wind hybrid energy system (SWHES) proposed here is shown in Figure 5. Using a controller, the wind turbine and solar panel could be combined to

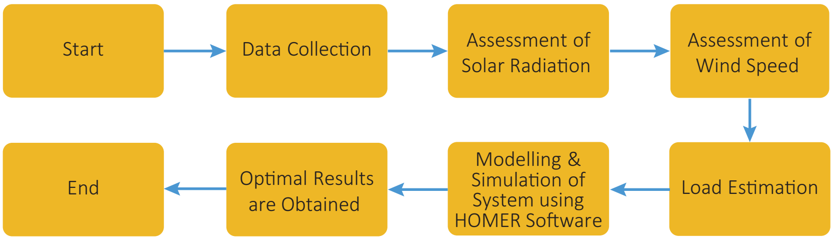

Figure 4: Process flow diagram for research

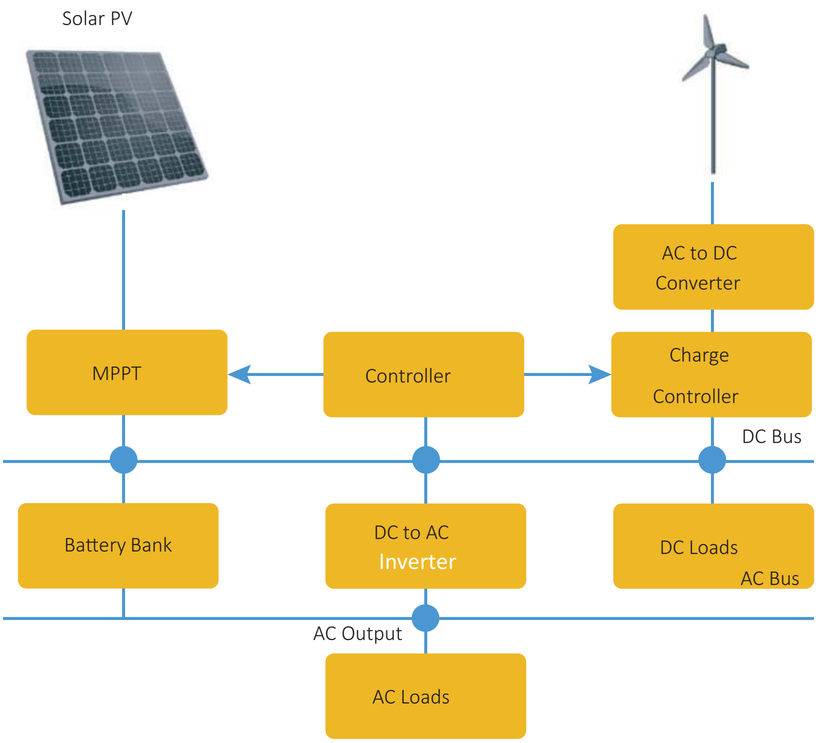

Figure 5: SWHES block diagram

charge a battery. The charge controller helps in regulating the charging process before it is stored in the storage medium. An inverter helps in converting direct current (DC) output voltage of the storage into alternating current (AC) voltage for AC loads. If one of the systems failed to generate power, for example, if the PV system is unable to generate power at night, then the wind system will supply the power which gets stored in the battery bank, resultantly this system maintains the continuity of power supply. The load monitoring is done by using a specific algorithm which is coded into the charge controller.

Site selection and resource assessment

A survey conducted by the Indian Ministry of New and Renewable Energy served as the basis for site selection. Gujarat was found to possess a wind potential with 84.43 GW at 100 m height. The state is also placed at number five in terms of solar potential with 2654 MW (NS Energy 2021). Hence, Gujarat is an ideal location to set up the SWHES. Since the research was focused on electrification of rural areas, Vighakot village near Kutch district of Gujarat was chosen as the site for deployment.

Wind speed assessment

Wind data of Vighakot site from January 2020 to December 2020 was used for analysis. The data for this period was collected from NASA Prediction of Worldwide Energy Resource (POWER) database. The annual average wind speed at 50 m height was estimated to be 6.15 m/s. In Figure 6, the monthly fluctuation in wind speed is depicted graphically. From the figure, it can be noted that higher wind speeds occur during April to September with wind speed of above 6 m/s, while lower wind speeds occur from October to December and during the first three months of the year, wind speed is less than 6 m/s. Hence, the deployment of wind turbine at this location is ideal.

Solar radiation assessment

Solar data of Vighakot site from January 2020 to December 2020 was collected from National Renewable Energy Laboratory (NREL) database. The annual average solar radiation was found to be 5.50 kWh/m^2/day. In Figure 7, the monthly fluctuations in solar radiation is depicted graphically. It can be seen from the figure that higher solar radiation occurs during March to June and other months had radiation less than 6.00 kWh/m^2/day. The clearness index ranges from 0.47 to 0.64, indicating that all the months are sunny, and no month is very cloudy. A clearness index of 0.25 indicates a very cloudy month, but Vighakot does not display this value. Hence the site is ideal for solar PV deployment.

Load estimation

Before designing the hybrid system, it is vital to determine the load demand from the system. The daily load profile indicating load vs operation hour of the day of a household is shown in Figure 8 (a). The total energy demand expected from the whole system during a weekday was determined to be 1.09 kWh. The daily load profile for a weekend is shown in Figure 8 (b), and it was determined that the system's overall weekend energy consumption

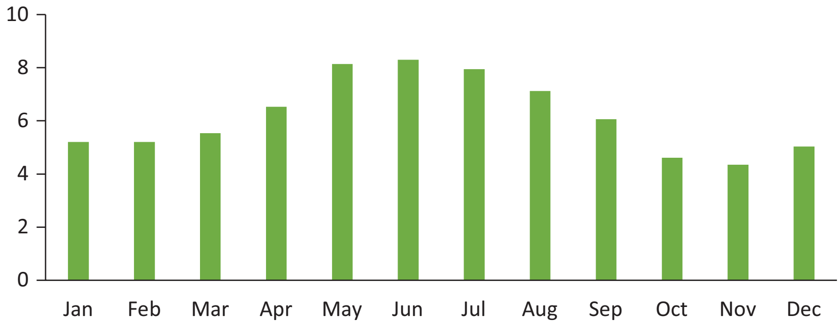

Figure 6: Monthly average wind speed pattern in Vighakot

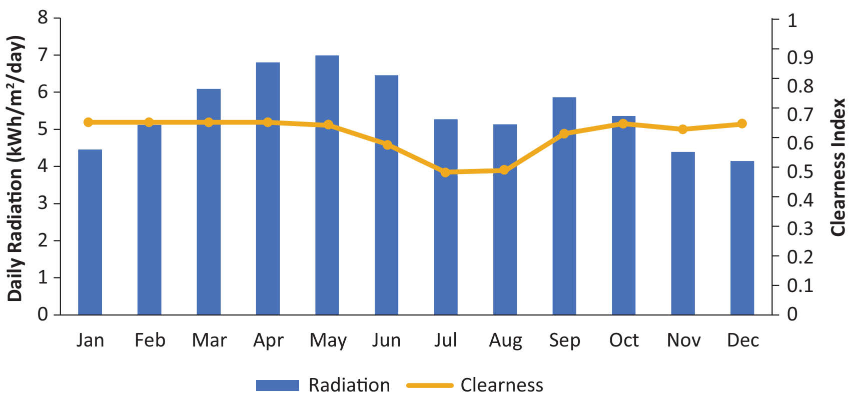

Figure 7: Monthly average solar radiation pattern in Vighakot

was 2.15 kWh. Considering 30 days in a month, with 22 weekdays and 8 weekends, the monthly energy demand of one household is estimated to be about 41.18 kWh which is in the range of the energy consumption (39.9 kWh) of an average rural household in India. So, for designing of the system, weekend power demand is considered to be higher. To ensure that the system is always effective for producing energy, each of the two energy generators is designed to be able to provide a minimum quantity of power more than the peak demand at any given moment. A detailed split of load and energy calculation for a single household is summarized in Table 1. This load data is used by HOMER model for system design and analysis.

System component details

The SWHES comprises various components which include solar and wind generators, charge controller, battery bank, inverters, and AC to DC converters.

Solar PV system

A PV matrix is created by connecting PV cells in a series–parallel pattern. Figure 9 represents a modelled circuit with single ideal diode.

Wind energy conversion system

The wind energy conversion system comprises a wind turbine, permanent magnet synchronous generator (PMSG), and wind maximum power point tracking (MPPT) mechanism. Electricity generated from a wind turbine is based on the amount of wind speed available in the region, where the turbine is placed along with the mechanical coupling of the rotors to an electric generator.

Charge controller

The primary duty is to regulate whether a source should be active or inactive. When a PV panel is connected to a load, the output usually does not stay

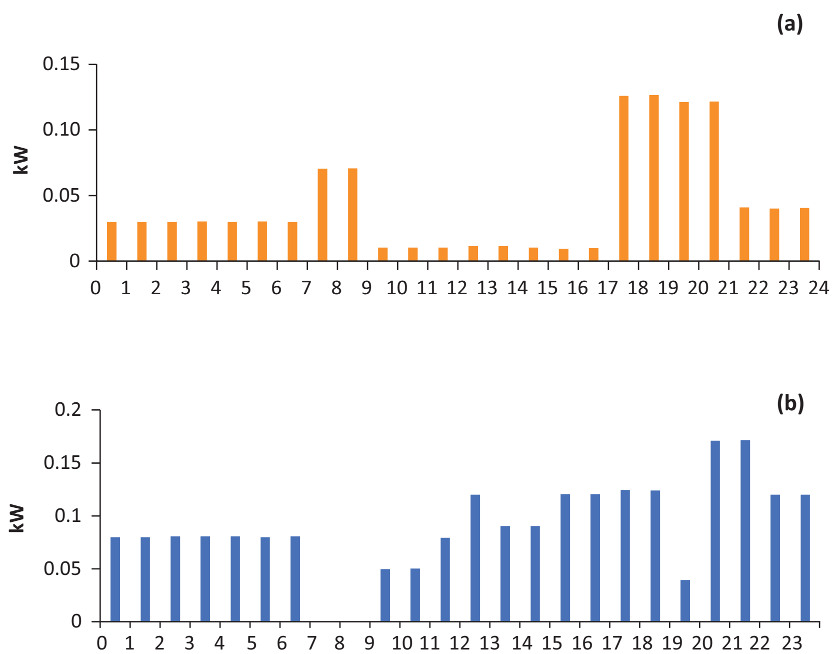

Figure 8: Daily load profile in the household during: (a) weekday and (b) weekend

Table 1: Estimated energy demand of various appliances in the household

Appliance	Quantity	Power rating (W)	Total Load demand (W)	Hours of operation (h)	Daily energy demand (Wh)
During a Weekday					
Fan	2.00	40.00	80.00	8.00	640.00
Lighting	4.00	10.00	40.00	6.00	240.00
Television	1.00	50.00	50.00	4.00	200.00
Other accessories	2.00	2.50	5.00	2.00	10.00
Total			175.00		1090.00
During a Weekend					
Fan	2.00	40.00	80.00	17.00	1360.00
Lighting	4.00	10.00	40.00	12.00	480.00
Television	1.00	50.00	50.00	6.00	300.00
Other accessories	2.00	2.50	5.00	2.00	10.00
Total			175.00		2150.00

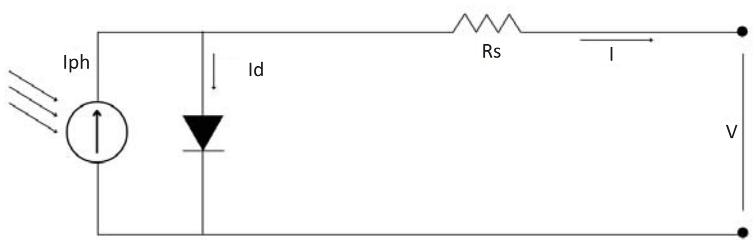

Figure 9: PV model with a single diode

constant since the sun irradiation varies during the day. Therefore, backup systems are used to supply the need for electricity under such circumstances. These charge controllers monitor when the battery should be charged and when to be disconnected from the power supply.

Battery energy storage system

The battery energy storage system is used to aid the hybrid system in ensuring smooth and stable functioning, as well as keeping a steady voltage during power generation and consumption mismatches.

Inverter

Power inverters transform electrical energy from DC form to AC form. Its goal is to maintain equilibrium in the flow of electricity through the DC and AC components. The stand-alone inverters are suited for use in remote locations since they are made to run on independent, utility-free power systems. Efficiency of an inverter for converting DC to AC is about 90% or greater.

Selection of system components

The following assumptions are considered for selection of system components:

a. Inverter efficiency = 90%
b. Battery capacity = 45 V
c. Sunlight available = 7 h/day
d. Operating factor of PV module = 0.8
e. Coefficient of performance for wind turbine = 0.4
f. Capacity factor for wind turbine = 0.3
g. Density of air = 1.168 kg/m^3

Wind turbine and solar PV selection

Based on analytical calculations for each component and using the above assumptions, the required sizing of wind turbine and solar PV panel for the SWHES was carried out. The wind turbine selected is AWS HC 650; its power curve is depicted in Figure 10. The selected solar panel is Trina Duomax PEF14 which is a residential-scale polycrystalline module with 72 cells. For the designed system only one solar module and wind turbine were needed to be used in combination with the wind turbine. The specifications of the wind turbine and solar panel are given in Tables 2 and 3, respectively.

Table 2: Specifications of wind turbine

Rated capacity	650 W
Rated wind turbine voltage	12–48 V
Cut-in wind speed	2 m/s
Blade number	3
Rotor diameter	2.20 m
Cut-out wind speed	8.5 m/s
Hub height	12 m
Tip speed ratio	8.50

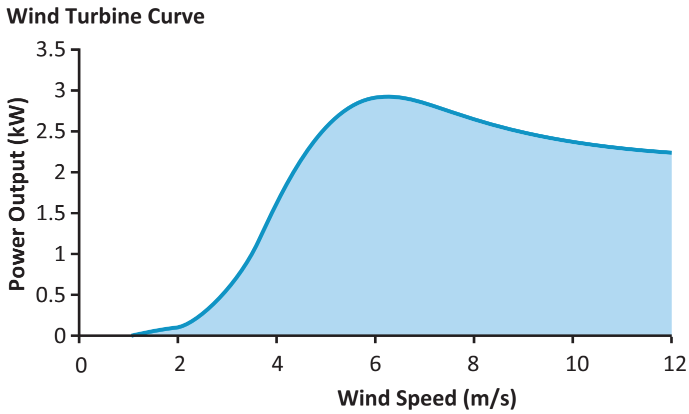

Figure 10: Power curve for AWS HC 650

Table 3: Specifications of solar panel

Rated capacity	320 W
Maximum power voltage	37.20 V
Maximum power current	8.60 A
Open circuit voltage	45.40 V
Short-circuit current	9.23 A
Module efficiency	16.30%
Module dimensions	1978 × 992 × 6 mm
Nominal operating temperature	44°C

Inverter and battery selection

The inverter and battery selected were Kirloskar KSG-I-1K and BAE Sundepot 48-350, respectively. The selection is compatible with the whole hybrid system and its specifications are listed in Table 4 and 5.

Table 4: Specifications of inverter

Maximum input power	1 kW
Input voltage	48 V
Input current	10 A
Power factor	1
Efficiency	90%

Table 5: Specifications of battery

Nominal capacity	320 Ah
Nominal voltage	48 V
Minimum state of charge	20%
Storage capacity	6 kWh
Efficiency	90

System Simulations

The operation of a system architecture plotted in HOMER determines if the designed system can meet the electric demand under the specified conditions. Optimization, simulation, and sensitivity analysis are the three functions carried out using HOMER. The specifications of the selected components are incorporated once all the key components are first introduced to the software interface. The solar and wind resource data like the average wind speed and solar irradiance data are fed into the software. The system architecture made in the software is shown in Figure 11.

The overall power generation of components are listed in Table 6. It was discovered that each power source contributes a specific proportion of the overall power, depending on the component specifications. The wind turbine could generate a higher share

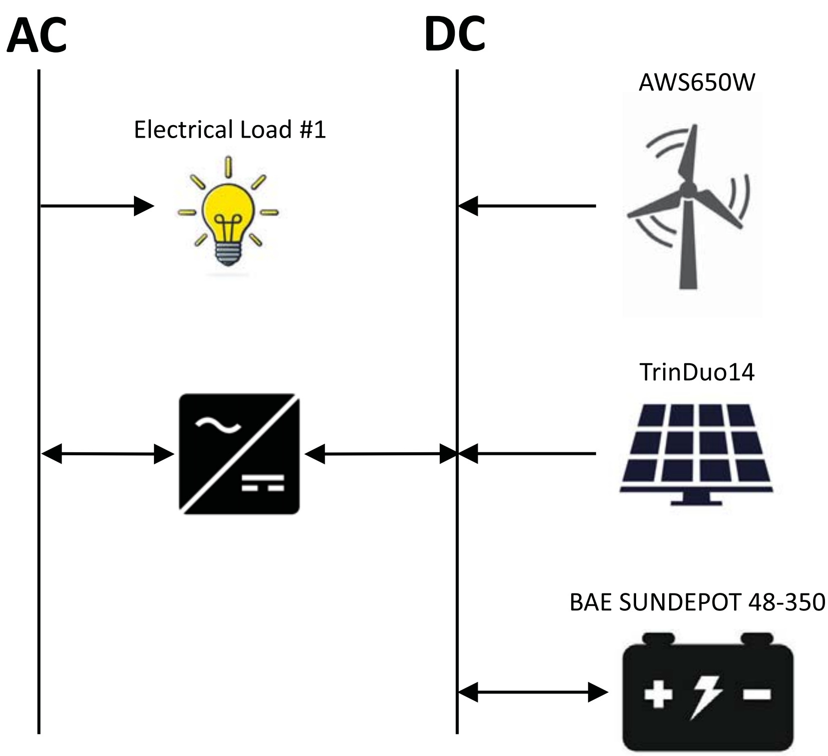

Figure 11: System architecture

Table 6: Energy production contribution of each power source

Production	kWh / year	Percentage
Trina Duomax PEG14	728	24.4
AWS HC 650	2259	75.6
Total	**2987**	**100**

The results for the wind turbine showed that the mean output after considering all the losses was 258 W with a capacity factor of 39.7%. The total energy production from the wind turbine was found to be 2259 kWh/year and it can operate up to 8620 hour/year. The minimum and maximum power outputs from the turbine were 0 W and 658 W, respectively. Figure 13 displays the wind turbine output variation for a year and it is clear from the DMapp that the wind energy is unevenly distributed in a day, but it still can be utilized successfully with the help of battery banks used in the system as energy storage device.

It is also to be noted from Figure 14 that the battery can sustain a good state of charge (SOC) of 90% to 100% throughout the year. The battery's

with 2259 kWh/year, since the capacity of this component was on the higher side compared to solar PV module.

The average output in respect to the panel's rated capacity served as the foundation for the PV panel results. Average output was determined to be 80.31 W with a 20% capacity factor. Both temperature and solar irradiation in Vigakot were taken into consideration to obtain the optimum results of energy production from the solar panel. The solar panel was estimated to operate for 4378 hours/year with PV penetration of 92.8%. The minimum and maximum outputs from the PV panel were 0 W and 405 W, respectively. Solar PV panel's DMapp is shown in Figure 12, and it is evident that the panel is able to provide adequate power for an entire year as long as there is sunlight.

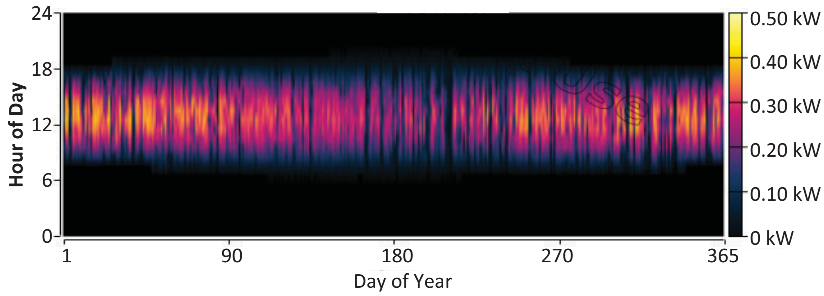

Figure 12: PV output variation throughout the year

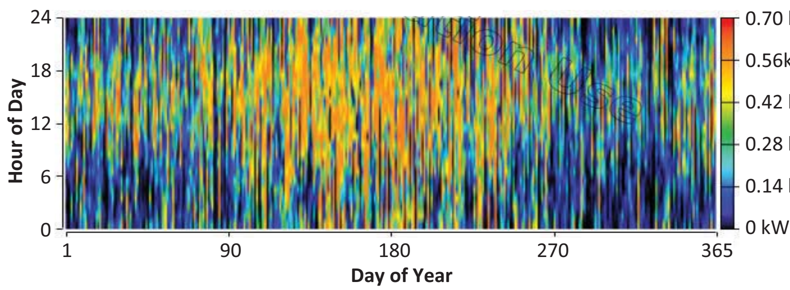

Figure 13: Wind turbine output variation throughout the year

performance is significant since the hybrid system and depends heavily on the battery's SOC, which maintains a steady supply to the loads.

The monthly simulation of the system demonstrates a good supply of electricity for a year. Hence this system can be used to power off-grid rural households. From Figure 15, it can be concluded that months of October and November have the lower simulated energy production, however, this can be taken care of since the battery used in this design is of a higher storage capacity which is shown by the SOC plot.

The simulated hybrid system is projected to produce a total of 2987 kWh/year of energy which is about 8.1 kWh/day. After considering all the system losses, it can be established, each household would require around 2.5 kWh/day, hence, this designed system can be deployed at the location for usage. So, it can be concluded that the designed SWHES is reliable and can produce continuous and constant power supply to the loads without any fluctuations. EF

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» NS Energy 2021. Profiling the top five states for solar power production in India. Details available at <www.nsenergybusiness.com>

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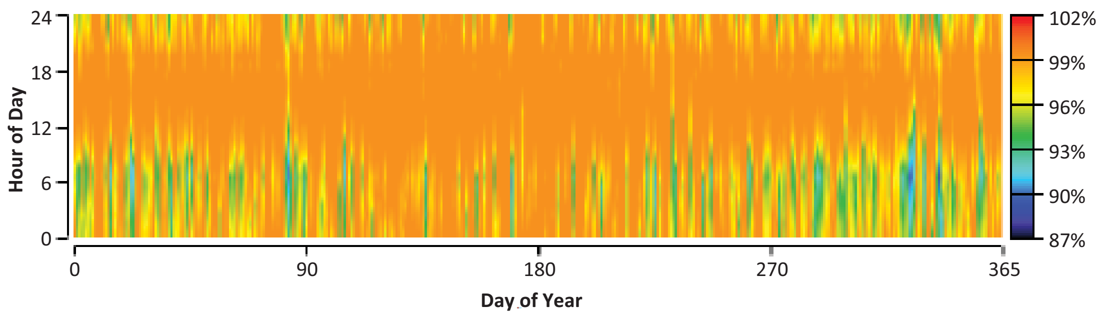


Figure 14: Battery SOC throughout the year

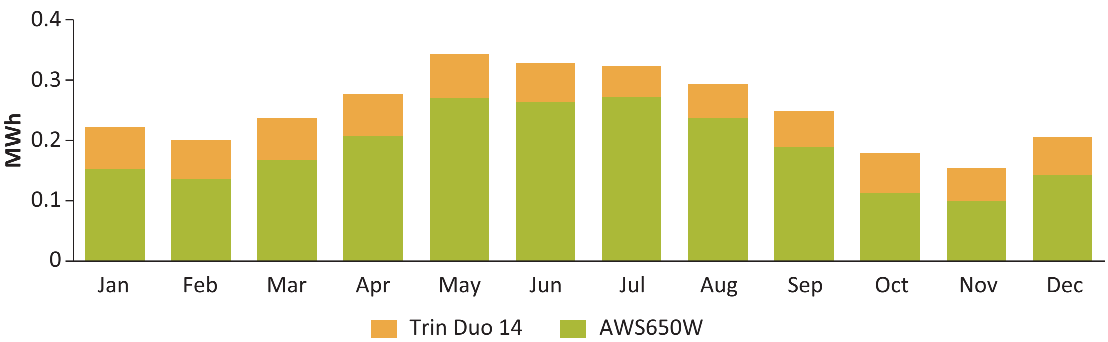


Figure 15: Simulated monthly average energy production for the hybrid system

THE ROAD TO A SMARTER, GREENER PLANET

Both as individuals and on the organizational level, many are devoted to turning green and efficiently achieving net zero. However, misguided efforts on these fronts can lead to higher emissions and a waste of potential. Here, we are in conversation with **Tanya Singhal**, Founder of **Mynzo Carbon and SolarArise**. Both these ventures do just that—providing guided solutions to reducing one's carbon footprint and expanding renewable capacity.

Could you provide an in-depth exploration of the connection between human activities and carbon emissions?
Climate change is a complex interplay between natural processes and human activities. It is a known fact that earth has an atmosphere with greenhouse gases that maintain an ideal temperature needed for the survival of human life. This is why earth is often called the 'Goldilocks' planet—its conditions are just right, not too hot or too cold, allowing life to thrive. These gases produce a natural greenhouse effect, which maintains an average temperature. However, since the post-industrial era human activities like burning fossil fuels, deforestation, industrial processes, etc., have increased these greenhouse gases: destroying the balance and overheating the earth too much. Scientists warn that surpassing a 1.5 degree Celsius temperature rise could have dire consequences, with impacts already evident in more frequent extreme weather events and melting glaciers.

Please shed light on the carbon impact of our daily activities. How do you offer individuals and companies a pathway to diminish and recapture carbon emissions?
Our daily activities significantly contribute to carbon emissions, impacting the environment. To understand and reduce carbon emissions, measurement of one's carbon footprint is key. How can you reduce something you can't measure? For individuals, simple actions like driving cars, consuming electricity, and even food choices and purchases release carbon into the atmosphere. For companies, it is a combination of their direct actions (Scope 1 and 2) like their fleet, equipment, buildings, electricity consumption, etc., and more indirect actions (Scope 3) like their suppliers and users (upstream and downstream emissions), their employees' emissions, etc. Knowing one's climate identity enables one to comprehend the magnitude of their contribution to climate change and empowers one to take subtle steps towards reducing their emissions, without drastically changing their business or lifestyle.

At Mynzo, we first help individuals and companies measure their emissions. Our technology leverages cutting-edge algorithms and data analytics to automatically calculate an individual's carbon footprint based on their activities. These emissions can be subdivided into personal and professional emissions, where the latter is then summed across an organization to give the organization's employee emissions—a major part of their Scope 3 emissions. Our platform also delivers at-the-moment nudges, offering tailored recommendations and a way to build your own forest (assets and not offsets)

to help corporates, communities, and individuals get to net zero.

Walk us through Mynzo Carbon's technology-driven solution that enables individuals to comprehend their impact on the world and empowers them to make changes capable of altering our trajectory.
By utilizing a phone's inbuilt sensor data, we capture all the individual's activities (without the need for any manual data entry) and convert them into their carbon footprint. Based on this data we provide real-time, personalized insights for reduction in emissions by subtle changes in lifestyles and planned infrastructure changes. However, not all emissions can be reduced. For balance emissions, we help recapture them.

Mynzo believes it is best to build long-term recapture assets, as opposed to purchasing one-time credits as an immediate transaction. Whatever cannot be reduced needs to be recaptured with assets, not offsets. Offsets were a creation of the regulatory framework to help ease the process of transition (and for some to delay it as much as possible). Instead, corporates and individuals should be building assets that take carbon out of the air. Within assets, focus on forests, not trees: the most insipid application of the 'offsets' approach is planting trees (plant and forget). This has led to the promotion of bad habits like greenwashing, ecological degradation, and lifestyle impact. Instead, a 'Forest' approach creates a system that is appropriate for the local soil, history, and environment, as well as provides for improved livelihoods for local populations. This more holistic and long-term approach leads to better survivability and carbon recapture. Each corporation or individual can have their very own forest, with their name, that is planted and managed by Mynzo and its partners. Through a circular economy concept, the fruits of the plantation belonging to the farmer—who then ensures their longevity and carbon sequestration—is assigned to the corporate/individual.

Could you share insights into SolarArise's efforts in transforming abandoned land into affordable, clean sources of solar power?
At SolarArise, we specialize in transforming uninhabited land (in the middle of nowhere) into productive solar power sources. Our process involves identifying large pieces of uninhabited areas with good solar radiation and constructing MWs of solar plants on them. These plants are then connected to nearby sub-stations to distribute electricity to the grid. By repurposing abandoned land, we not only generate clean energy, but also provide employment opportunities to nearby communities. Our efforts contribute to powering the grid with

affordable, sustainable electricity, while revitalizing underutilized landscapes.

How do you integrate your technical, financial, and developmental expertise to construct a portfolio of solar plants, ensuring that they yield low-risk returns for investors and simultaneously challenge the prevailing dominance of fossil fuels?
Building a solar plant is a combination of multiple skills. Firstly, thorough technical analysis ensures optimal plant design, as well as performance and procurement choices to get the most power output with minimum costs. Financial acumen comes into play for raising both the debt and equity needed for the projects. Solar involves a high upfront capital investment. So, structuring equity investment models that attract investors while ensuring profitable returns and leveraging it with low-cost project finance debt is key. Understanding developmental dynamics aids in navigating regulatory frameworks, winning the right auctions, and fostering smooth project execution.
By balancing these elements, we optimize plant performance and financial viability, attracting investors seeking sustainable returns. This is how solar has now transformed from 18 rps/unit in 2010 to 2–3 rps/unit today and is no longer a marginal sector dependent on subsidies; but fully economically viable and ready-to-take fossil fuels head-on.

Recognizing the pivotal role of storage in enabling round-the-clock renewable power and bolstering electric vehicle adoption, India needs strategic investment in research and manufacturing of efficient storage technology. Did the Union Budget 2024 meet the expectations of the renewable energy industry in India?
The Union Budget 2024 was an interim budget and largely silent on big measures for renewables or storage. India has already, under the G20 presidency, shown its focus on renewables by committing to triple its renewable capacity by 2030. It did emphasize in the budget that it is important to reach the net zero goals and highlighted the importance of rooftop solar, especially for the poor and middle class, to increase energy access. EV has strong momentum, amid the PLI

scheme incentivizing its installation and with greater adoption of electric buses and widespread charging infrastructure.

Despite the introduction of LiFE (Lifestyle for the Environment) and the Green Credit Scheme, broad acceptance of green initiatives has been limited. How do you envision fostering widespread adoption of green initiatives in India in the financial year 2024–25?

To foster widespread adoption of green initiatives in India, we need a multifaceted approach. Firstly, enhancing awareness and education about the benefits of green practices is crucial. This includes educating individuals and businesses about the positive environmental and economic impacts of adopting sustainable lifestyles.

Secondly, more education on the available green financial incentives in LiFe and the Green Credit scheme can encourage participation. Making these incentives more real-life, like offering tax benefits or subsidies for green investments and purchases (as in the recent Pradhan Mantri Suryoday Yojana), can make them more appealing. Thirdly, integrating sustainability into mainstream culture and business practices can normalize green behaviors. This involves promoting sustainability as a core value across industries and encouraging companies to prioritize environmental responsibility. Lastly, leveraging technology and innovation to make green solutions more accessible and affordable can drive adoption. By implementing these strategies collaboratively, we can accelerate the widespread adoption of green initiatives in India in the financial year 2024–25. EF

CURRENT R&D RENEWABLE

A new three-phase eleven level packed e-cell converter for solar grid-tied applications

e-Prime—Advances in Electrical Engineering, Electronics and Energy **4**: *100152*
Sanjay Upreti, Bhim Singh, Narendra Kumar

A new three-phase eleven-level packed E-Cell (PEC11) converter is formed by selecting a quintuple ratio (1:5) between the voltages of solar photovoltaic arrays. The converter consists of three solar panels per phase; highest level of staircase voltage is achieved by the top solar panel. The subsequent voltage levels are obtained using an algebraic formulation with lower two solar panels. The operating modes to get each level are explained. The mathematical modelling is presented with voltage and current equations of three-phase grid. PEC11 converter feeds the current to the grid with closed-loop proportional-resonant (PR) controllers. The nearest level modulation (NLM) technique generates the gating pulses for PEC converter. It provides minimum switching loss and simple control in grid tied mode. This system is simulated in MATLAB/SIMULINK platform, and the power is fed smoothly in both steady-state and dynamic conditions. These results are validated in the real-time simulator (OPAL-RT), which makes this converter ideal for solar applications. EF

Keywords: Solar photovoltaic, packed e-cell, power quality, renewable energy, nearest level modulation

Optimum design and techno-socio-economic analysis of a PV/biomass-based hybrid energy system for a remote hilly area, using discrete grey wolf optimization algorithm

Sustainable Energy Technologies and Assessments **57**: 103213
Saikat Saha, Gaurav Saini, Anurag Chauhan, Subho Upadhyay, Rajvikram Madurai Elavarasan, M S Hossain Lipu

Un-economical grid extension in remote locations has motivated to the creation of stand-alone systems that are inexpensive and reasonably efficient. Renewable sources, such as solar energy and biomass, are easily available in remote and rural areas which can be utilized to fulfil the energy demands. In the present paper, a PV-biomass-battery-based hybrid system is considered for an un-electrified village located in Indian state of West Bengal. A novel design of hybrid energy system has been investigated under the technical, social, and economic constraints of the context. Further, two distinct resource scenarios have been considered and compared based on system cost. Further, 12 combinations of batteries and PV panels available in market are considered. The discrete grey wolf optimization (DGWO) algorithm has been used to investigate the optimal sizes and the system net present cost (NPC). Based on the findings, it is deduced that Scenario-2 (Biomass-solar-battery-based hybrid system) yields the lowest NPC of USD 159,648.70 at the levelized cost of energy of USD 0.0712/kWh. EF

Keywords: Annualized cost, cost of energy, discrete grey wolf optimization (DGWO), renewable energy, solar energy

Lignin-containing nanocelluloses (LNCs) as renewable and sustainable alternatives: prospects and challenges

Sustainable Energy Technologies and Assessments **41**: 1008308
Anuj Kumar, Ankur Sood, Pralay Maiti, Sung Soo Han

Lignin-containing nanocelluloses (LNCs), with adjustable lignin contents, have shown much attention to be utilized in different industrial and biomedical applications due to their renewable and sustainable nanotechnology. Therefore, there is a need to foster process technologies for producing lignin-containing nanocelluloses (LNCs), which are eco-friendly, cost-effective, sustainable, and can be utilized for wider industrial or biomedical applications. In this precise review, the authors provide an overview of fundamental challenges and opportunities in production of LNCs and their diverse end-use applications. EF
Keywords: Circular economy, biomaterials, lignin, nanocellulose, sustainable chemistry, renewability

Policy design for making India *Atmanirbhar* (self-sufficient) in green energy technologies

The Electricity Journal **36 (4)**: 107264
Gireesh Shrimali, Abhinav Jindal

In this paper, the authors suggest how India can become *Atmanirbhar* (i.e., self-reliant) in development of green energy technologies—solar, battery storage, and green hydrogen—given its stated commitments in clean energy. First, a generalized policy design is introduced. It is a set of ten policy measures: seven necessary and three sufficient, with the former being on the supply side and the latter on the demand side. The paper argues that while the ideal policy mix would be technology dependent, based on technology maturity and the strategic positioning of the country, it should draw both from supply side (i.e., for domestic development) and demand side (i.e., for scale deployment). The authors suggest the required individual strategies for each of the three technologies, such as—a manufacturing focused policy for solar solely to develop competence in manufacturing; a bottom-up, manufacturing-led policy for battery storage, with a focus on deployment in parallel with technology development; and traditional top-down, research-led strategy for green hydrogen by entering via development through supply side and complementing via deployment through demand side. Finally, these strategies are compared with the existing domestic energy industrial policies, as well as those prevalent in other jurisdictions such as the US and China. EF
Keywords: Atmanribhar, deployment, green energy technologies, India, policy design, self-sufficient

Introducing a new measure of energy transition: Green quality of energy mix and its impact on CO_2 emissions

Energy Economics **122**: 106702
Chi Keung Lau, Giray Gozgor, Mantu Kumar Mahalik, Gupteswar Patel, Jing Li

This paper introduces a novel measure of energy transition, i.e., the green quality of energy mix (GREENQ) across the Organization for Economic Co-operation and Development (OECD) countries. Then, the paper examines the impact of the GREENQ on CO_2 emissions in the panel dataset of 36 OECD countries, from 1970 to 2021. The explanatory variables include per capita income, institutional quality, and technology. Long-run panel data estimations indicate that these variables increase CO_2 emissions. The novel evidence is that the GREENQ is negatively related to the level of CO_2 emissions. These findings are robust to employ different panel data estimation techniques. Potential policy implications are also discussed in the paper. EF
Keywords: CO_2 emissions, green quality of energy mix, GREENQ, institutional quality, technology, panel data estimations

Renewable energy potential towards attainment of net-zero energy buildings status: a critical review

Journal of Cleaner Production **405**: 136942
S Christopher, M P Vikram, Chirodeep Bakli, Amrit Kumar Thakur, Y Ma, Zhenjun Ma, Huijin Xu, Pinar Mert Cuce, Erdem Cuce, Punit Singh

Global warming, climate change, and resource depletion have forced us to reconsider energy usage and efficiencies over the last few decades. Residential and commercial buildings are both large energy consumers, so improving energy and material usage efficiency in this sector is a common research topic. According to a recent study, the building sector (BS) accounts for 40% of greenhouse gas emissions. The primary objective of this paper is to examine and assess the potential

of renewable energy systems (RES) and their combinations for enhancing energy efficiency in the BS. Specifically, the focus will be on converting low energy-efficient buildings into highly efficient ones. The potential of the RES and their combinations for the BS is evaluated based on payback durations, energy generation, and reduction of CO_2 emissions. The optimization flow charts for the RES, feasibility studies, commercialization road maps of energy storage systems, and the necessity of control mechanisms for enhancing RES efficiency are discussed. Additionally, the technology drawbacks are discussed, along with various innovative techniques recommended to direct future study in this area. Finally, this article assists the audience in the selection of the right combination of potential RES, based on different conditions to achieve deep decarbonization in BSs. EF

Keywords: Net-zero energy buildings, decarbonization, global warming, climate change, renewable energy, energy

Modelling an off-grid hybrid renewable energy system to deliver electricity to a remote Indian island

Energy Conversion and Management **281**: 116839

Dibyendu Roy

The study examines numerous off-grid hybrid renewable energy system (HRES) combinations to deliver electricity to a remote island settlement. Six different configurations were subjected to technical, economic, environmental, and social analyses in order to establish the best optimal design. The best-optimized system's sensitivity analysis was carried out. Furthermore, different machine learning models have been applied to predict the performance of the system. In terms of economic assessments, the lowest levelized unit cost of electricity (LCOE) (USD 0.31/kWh) and highest return on investment (ROI) (26.4 %) make System 6 much more competitive. Despite the fact that System 6 is partially powered by a diesel generator, the life cycle CO_2 emissions (LCE) of System 6 and System 3 are at similar levels—49517.68 kg/year and 46744.45 kg/year, respectively. For system 6, it was observed that a 30 % rise in diesel fuel prices increased the net present cost (NPC) and LCOE by 4.9 % and 4.8 %, respectively. Matern 5/2 GPR model is found to be the best option among all the studied machine learning models for predicting renewable fraction and levelized unit cost of electricity. EF

Keywords: HRES, LCOE, power generation, economic analysis, solar energy, machine learning

A detailed review on sole and hybrid solar chimney based sustainable ventilation, power generation, and potable water production systems

Energy Nexus **10**: 100184

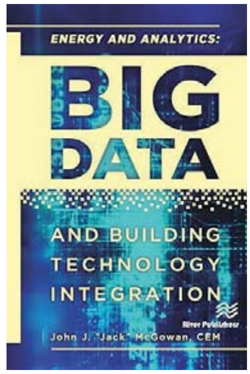
H Sharon

In this article, the potential of solar chimney technologies for building ventilation, power generation and potable water generation in sole, hybrid, and poly-generation modes has been reviewed extensively; by highlighting their optimal configuration, pros, cons, and economics. Solar chimney ventilation system in combination with evaporative cooler and earth-air heat exchanger can save at least 20 to 75% of the energy consumed for space conditioning. A sole solar chimney power plant occupies huge land area and has efficiency of only 1.0%. However, under hybrid and poly-generation operation modes its efficiency has improved to 55%. Solar PV modules seem to be a suitable partner for solar chimney technologies and enhance utilization by providing extra electric power output. Solar PV modules have been suggested as absorbers for ventilation systems and canopies for solar chimney power plants. However, proper thermal management of PV modules is essential for proper functioning under the conditions inside the former system. Geo-thermal energy, waste heat energy from thermal power plants, and flared gas from oil extraction sites can be utilized in solar chimney power plants to increase its operation time even after sun-set hours without any major modifications. Solar chimney based atmospheric water extraction systems enhance the micro-climate of sites and are highly suitable for applications in arid regions. Solar chimney ventilation systems are commercial and form an integral part of green buildings and net-zero buildings. On contrary, most of the literature on power generation and water production with solar chimney technology is theoretical; hence, more practical studies are needed to justify their reliability. EF

Keywords: Solar energy, sustainable architecture, solar chimney, waste heat, PV module, desalination

Energy and Analytics: Big Data and Building Technology Integration

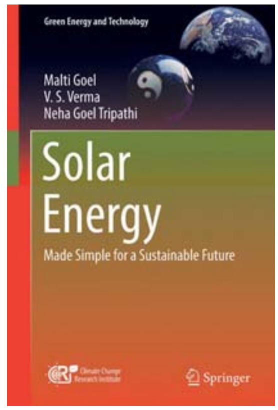
This book details how to leverage big data style analytics to manage and coordinate the key issues in both energy supply and demand. It presents a detailed explanation of the underlying systems technology that enables big data in buildings and how this technology provides added cost benefit from onsite solar, and electricity markets. It is a primer on building automation systems standards, web services, and electricity markets and programs; as well as a complete tutorial on energy analytics hardware, software, and Internet-enabled offerings that energy managers must understand today.



Author: CEM McGowan
Publisher: *River Publishers*; 374p
Year: 2023

Solar Energy: Made Simple for a Sustainable Future

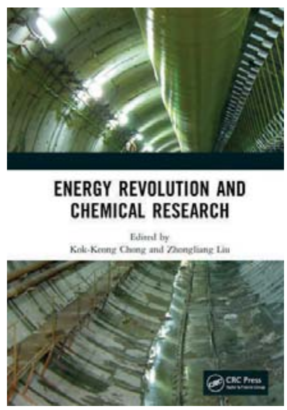
Solar Energy: Made Simple for a Sustainable Future presents the achievements made in solar energy and prospects in achieving solar potential in India. It covers the historical perspectives, innovations, and myriad applications of solar energy in its different forms. The book discusses solar devices and covers both solar photovoltaics and solar thermal energy and includes both heat and electricity applications. Solar policies in India, solar research, technologies, large-scale adoption as well as future trends are also discussed. This book will be useful for researchers and professionals with interests in technological, economical, and policy developments in solar energy-driven power industry.



Author: Roger Brown
Publisher: River Publishers; 210p
Year: 2023

Energy Revolution and Chemical Research: Proceedings of the 8th International Conference on Energy Science and Chemical Engineering (ICESCE 2022), China

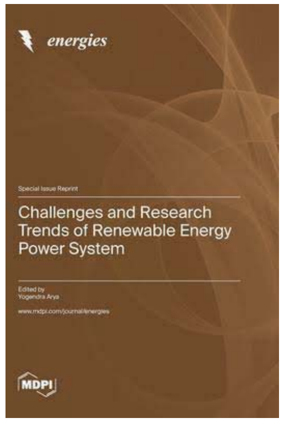
The conference conducts in-depth exchanges and discussions on relevant topics, such as energy engineering, environment technology, and advanced chemical technology, aiming to provide an academic and technical communication platform for scholars and engineers engaged in scientific research and engineering practice in the field of saving technologies, environmental chemistry, clean production, and so on. By sharing the status of scientific research achievements and cutting-edge technologies, it helps scholars and engineers all over the world comprehend the academic development trend and broaden research ideas; so as to strengthen international academic research, academic topics exchange and discussion, and promote the industrial incorperation of academic achievements.



Authors: Malti Goel, V S Verma, and Neha Goel Tripathi
Publisher: *Springer*; 188p
Year: 2023

Challenges and Research Trends of Renewable Energy Power System

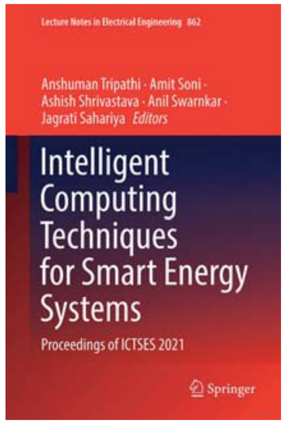
This reprint focuses on the current research trends in renewable energy sources (RESs) penetrated modern power systems (PSs). Various operational, power quality, and stability issues and their solutions are discussed comprehensively in RESs integrated PSs. The topics of attraction include islanding detection and prevention, frequency regulation, pricing-based multi-objective optimal scheduling, day-ahead load demand forecasting, advancing intelligent and robust optimization techniques-based control strategies.



Author: Yogendra Arya
Publisher: *MDPI*; 248p
Year: 2023

Intelligent Computing Techniques for Smart Energy Systems: Proceedings of ICTSES 2021

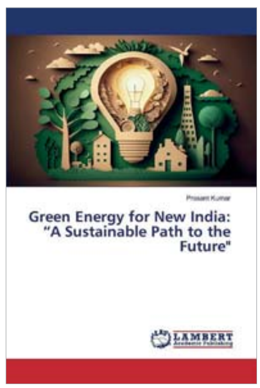
This book compiles the best selected research papers presented during the 2nd International Conference on Intelligent Computing Techniques for Smart Energy Systems (ICTSES 2021), held at Manipal University, Jaipur, Rajasthan, India. It presents the diligent work of the research community where intelligent computing techniques are applied in allied fields of engineering ranging from engineering materials to electrical engineering to electronics and communication engineering to computer-related fields. The theoretical research concepts are supported with extensive reviews highlighting the trends in the possible and real-life applications of computational intelligence. The high-quality content with broad range of the topics is thoroughly peer-reviewed and published on suitable recommendations.



Authors: Anshuman Tripathi, Amit Soni, Ashish Shrivastava, Anil Swarnkar, and Jagrati Sahariya
Publisher: *Springer*; 795p
Year: 2023

Green Energy for New India: A Sustainable Path to the Future

Green Energy for New India: A Sustainable Path to the Future is focuses on the concept of green energy and its potential for sustainable development in India. The book covers various aspects of green energy, such as renewable energy technologies, policies, strategies, and best practices for promoting sustainable energy in India. The publication discusses the importance of transitioning towards green energy sources to mitigate climate change, reduce greenhouse gas emissions, and achieve Sustainable Development Goals.



Author: Prasant Kumar
Publisher: *LAP Lambert Academic*; 60p
Year: 2023

RENEWABLE ENERGY TECHNOLOGY DEVELOPMENT

New Approach Shows Hydrogen can be Combined With Electricity to Make Pharmaceutical Drugs

In the pursuit of greener and more sustainable methods for chemical production, researchers at the University of Wisconsin-Madison have embarked on a pioneering journey by harnessing hydrogen fuel cell technologies. These technologies, already prevalent in powering electric vehicles, laptops, and cell phones, offer a promising avenue for reducing the carbon footprint of the chemical industry, a notorious energy consumer. The team sought to address the challenges posed by the conventional use of zinc as a source of electrons in chemical processes, which generates significant environmental waste.

Inspired by hydrogen fuel cells, they envisioned a green solution: adapting fuel cell technology to manufacture chemicals instead of electricity. By utilizing organic compounds like quinones and supercharging electrons with electricity, the team has demonstrated the feasibility of this technology, showcasing its ability to produce essential organic molecules and pharmaceutical ingredients.

- Hydrogen gas emerged as a prime candidate due to its renewable electricity generation and minimal waste production qualities.
- This innovative approach not only aligns with the broader hydrogen economy vision but also holds the potential to revolutionize

pharmaceutical manufacturing and extend its applications to various chemical processes.

With ongoing efforts to scale up the process for industrial use, this environmentally friendly chemical production method promises to make a significant impact on reducing the industry's carbon footprint and ushering in a cleaner, more sustainable era for chemistry.

Source: https://www.sciencedaily.com/releases/2023/08/230821174253.htm

Direct Power Generation from Methylcyclohexane Using Solid Oxide Fuel Cells

Researchers led by Professor Akihiko Fukunaga from Waseda University in Japan have developed a way to generate electricity directly from methylcyclohexane (MCH), an organic hydride used as a hydrogen carrier. MCH is a promising hydrogen carrier because it's liquid at room temperature, easy to transport, non-toxic, and has a higher hydrogen density than high-pressure hydrogen storage. Traditionally, the dehydrogenation of MCH to release hydrogen required energy-intensive processes and facilities. However, the research team achieved a remarkable feat by combining two processes within a fuel cell:

» Using solid oxide fuel cells (SOFCs) to simultaneously dehydrogenate MCH (endothermic) and generate electricity (exothermic) without the

need for separate dehydrogenation facilities.

» They operated the SOFC at a specific temperature to prevent pyrolysis of MCH and carbon deposition at the electrodes, efficiently producing toluene as a byproduct.

Furthermore, the researchers discovered that they could introduce oxygen groups into the aromatic structure using a fuel cell, revealing the potential for new synthetic chemistry applications. This approach reduces the energy required for hydrogen production and opens the door to sustainable hydrogen-based technologies, potentially revolutionizing energy solutions for the future.

Source: https://www.sciencedaily.com/releases/2023/08/230829125841.htm

Efficient Silicon Photocatalyst for Green Hydrogen and Biomass

Researchers have developed an innovative silicon-based photocatalyst that harnesses solar power to efficiently produce hydrogen and high-value compounds. This breakthrough addresses previous limitations, as the photocatalyst is non-toxic, eco-friendly, and highly responsive to sunlight. It overcomes challenges associated with toxic catalysts and oxide layer formation, achieving a remarkable 28-fold improvement in hydrogen production efficiency. Additionally, the technology can produce high-value compounds using biomass as a feedstock, ensuring long-term stability and opening new possibilities in energy applications. This advancement marks a significant step forward in green hydrogen production technology.

Source: https://www.sciencedaily.com/releases/2023/08/230829125841.htm

Engineers Develop an Efficient Process to Make Fuel from Carbon Dioxide

Researchers have developed an efficient process to convert carbon dioxide (CO_2) into formate, a versatile fuel that can be used in fuel cells to generate electricity. This breakthrough offers a more practical and sustainable approach to carbon capture and utilization, achieving a conversion efficiency of over 90%, far superior to conventional methods. The process involves the electrochemical conversion of CO_2 into stable potassium or sodium formate, which can be easily stored and transported. It has the potential for various applications, from individual homes to industrial and grid-scale uses, providing emissions-free heat and power.

Source: https://www.sciencedaily.com/releases/2023/10/231030141345.htm

Self-powered Microbial Fuel Cell Biosensor for Monitoring Organic Freshwater Pollution

Researchers have created a self-powered and affordable biosensor for monitoring water quality in freshwater lakes and rivers. This innovative biosensor is based on a floating microbial fuel cell (FMFC) that continuously tracks organic contamination levels. Using low-cost carbon-based materials, the FMFC harnesses electricity generated by electrogenic bacteria to indicate the presence of organic waste in water samples. An integrated LED visually signals contamination levels, making it a valuable tool for early detection of organic wastewater influxes in freshwater bodies, contributing to the protection of aquatic ecosystems.

Source: https://www.sciencedaily.com/releases/2023/11/231102135125.htm

Driving on Sunshine: Clean, Usable Liquid Fuels Made from Solar Power

A novel solar-powered technology has emerged, capable of converting CO_2 and water into highly efficient liquid fuels, namely ethanol and propanol, suitable for direct integration into automotive engines. These 'artificial leaves' employ photosynthesis to seamlessly transform CO_2, water, and sunlight into versatile multi-carbon fuels, offering a solution with remarkable energy density and ease of storage and transport. Crucially, these solar fuels yield zero-net-carbon emissions and are entirely renewable, eliminating concerns regarding diverting agricultural land from food production, a key issue associated with bioethanol.

Bioethanol, derived from plant sources rather than fossil fuels, is considered a cleaner alternative to gasoline. The majority of vehicles today rely on gasoline infused with up to 10% ethanol (E10 fuel). Notably, the United States leads global bioethanol production, with nearly 45% of its corn crop dedicated to ethanol production. EF

Source: https://www.sciencedaily.com/releases/2023/05/230518120808.htm

THE DECADE OF INDIA'S ENERGY TRANSITION

Vasudha Foundation has been coming out with the *Power Outlook Series* since 2020 to capture the key trends and developments in India's electricity and energy sector, with each of the volumes focusing on specific trending themes, ranging from an introduction to *India's Power Sector Value Chain* (Volume I) to *Capturing Key Headwinds and Tailwinds in India's Power Sector Decarbonization Journey* (Volume 4), which was brought out just before the Glasgow Climate Meeting of 2021, to the more recent volume, the Volume 8, which captures the trends and development in India's clean energy journey, in the last decade.

Each of the *Power Outlook Series* contains a fountain of data, information, and analysis produced in the form of graphs, infographics, and charts that in itself is very comprehensive.

The current volume of the *Power Outlook Series*, titled, 'Capturing a Decade of India's Clean Energy Journey' traces the growth of India's energy sector both in size and its composition besides showcasing as to how India has taken a leadership role in embarking on a low-carbon pathway, while addressing and mitigating the various challenges it faced in its journey. The last decade has been instrumental in shaping a clean energy transition for India. We have covered a considerable distance since 2012, making India the fourth-highest country in terms of deployment of renewable energy.

As India hosted the annual G20 meetings in September 2023, as part of the India Presidency of the G20, we felt that it is an ample opportunity for the nation to share its energy growth story to not only with the developed countries but also with developing counterparts, as many of them have started to embark on an energy transition journey and some are learning from the Indian experience and how it could benefit them in their planning.

Some of the key facets of India's energy growth journey and captured in the Volume 8 of the *Power Outlook Series* are:

1. **Ballooning energy demand and electricity consumption**: India is a massive country, adding almost ~20 million people and ~8 million new electricity connections each year over the past decade.
   » The primary energy supply increased from 581 million tonnes of oil equivalent (MTOE) to 739.4 MTOE, translating into a 27% increase in supply over the last decade.
   » The electricity consumption has risen at a rate of 5% per annum and nearly doubled itself in the last decade—785 billion units (BU) in FY2012 to1296 BU in 2022 (including captive).
2. **Power, transport, and industry formed over 70% share of the emission and energy demand sectors**: The highest growth was witnessed in road transportation and residential electricity consumption.
   » The transport sector is dominated by road transport and the ever-increasing demand for private cars resulted in the highest increase in sectoral energy consumption rising, from 0.8 exajoules (EJ) in 2011–12 to 2.4 EJ in 2021–22.
   » Rising standard of living with the massive electrification drive led to the highest increase in electricity consumption for the domestic sector, translating from 171 BU in 2011–12 to 334 BU in 2021–22 (at a CAGR of 6.9%).
3. **A reliable and cleaner power system**: The decade saw a phenomenal improvement in creating electricity infrastructure and improving shortages.
   » The installed electricity capacity has almost doubled, from 224 gigawatt (GW) in 2012–13 to 416 GW in 2022–23. Concurrently, the peak demand for electricity in India rose from 135 GW to 216 GW during the same period.
   » The renewable energy (RE) capacity more than doubled, from 68 GW by 2012–13 to 172 GW by 2022–23. This translates into an RE generation share of around 22%, up from 17% in 2012–13.
   » The peak demand shortages plummeted from 10.6% to 1.2%, and the electricity demand shortage has been reduced to a mere 0.4%.
4. **A move towards cleaner energy choices**: The Government has put large impetus on adopting cleaner energy choices. Initiative like Lifestyle for Environment, UJALA, UJJWALA programmes are all testimony to this.
   » Following the PMUY scheme, the use of LPG as a cooking fuel in the residential sector has seen a steady increase with its consumption share rising, from 62% in 2011–12 to 95% in 2021–22.
   » The electric vehicle (EV) ownership in the country has risen from almost 0 to 5% in 2022–23 of the total vehicles registered.
   » The UJALA LED programme brought a market transformation in the lighting sector.

- Rooftop solar recorded a phenomenal average growth rate of 57% since 2018–19, led by the commercial and industrial sector.

5. **Indigenizing of the clean energy sector**: To boost its industrial production and generate jobs for the clarion call of '*Atmanirbhar Bharat*', the Government of India announced multiple programmes such as Make in India, Production Linked Incentive (PLI) scheme to encourage domestic manufacturing in the clean energy sector.
   - The total number of solar PV manufacturers doubled itself to 59 manufacturers since 2018.
   - The number of EV manufacturers rose exponentially, from just 4 manufacturers in 2012–13 to 78 in 2022–23.
   - The wind turbine generator (WTG) manufacturing capacity has almost doubled since 2018 and reached to 15 GW in 2022.

Many key policy initiatives such as green hydrogen policy, offshore wind policy, biofuels policy, and draft carbon credit trading scheme established India's commitment to enable a stronger institutional and policy mandate for a greener future. While India has significantly risen from adding 4 GW per year in 2012–13 to 15 GW per year in 2022–23; it has a long way to go to where it must add around 40 GW per year between 2023 and 2030 to achieve its mammoth target of 450 GW RE by 2030. EF

DANFOSS AND GOOGLE ENTER INTO A STRATEGIC PARTNERSHIP ON AI AND ENERGY EFFICIENCY

Danfoss and Google recently announced a strategic partnership to make use of the latest advances in artificial intelligence (AI) and promote energy efficient solutions in data centres.

Under the partnership, Danfoss, the Danish multinational engineering group, will use Google Cloud's generative AI capabilities to optimize the customer experience, streamline internal work processes and improve productivity across the organization. This can be done, for example, by using gen AI to collect and surface information, automate knowledge, generate product descriptions, and create solutions with chatbots in e-commerce.

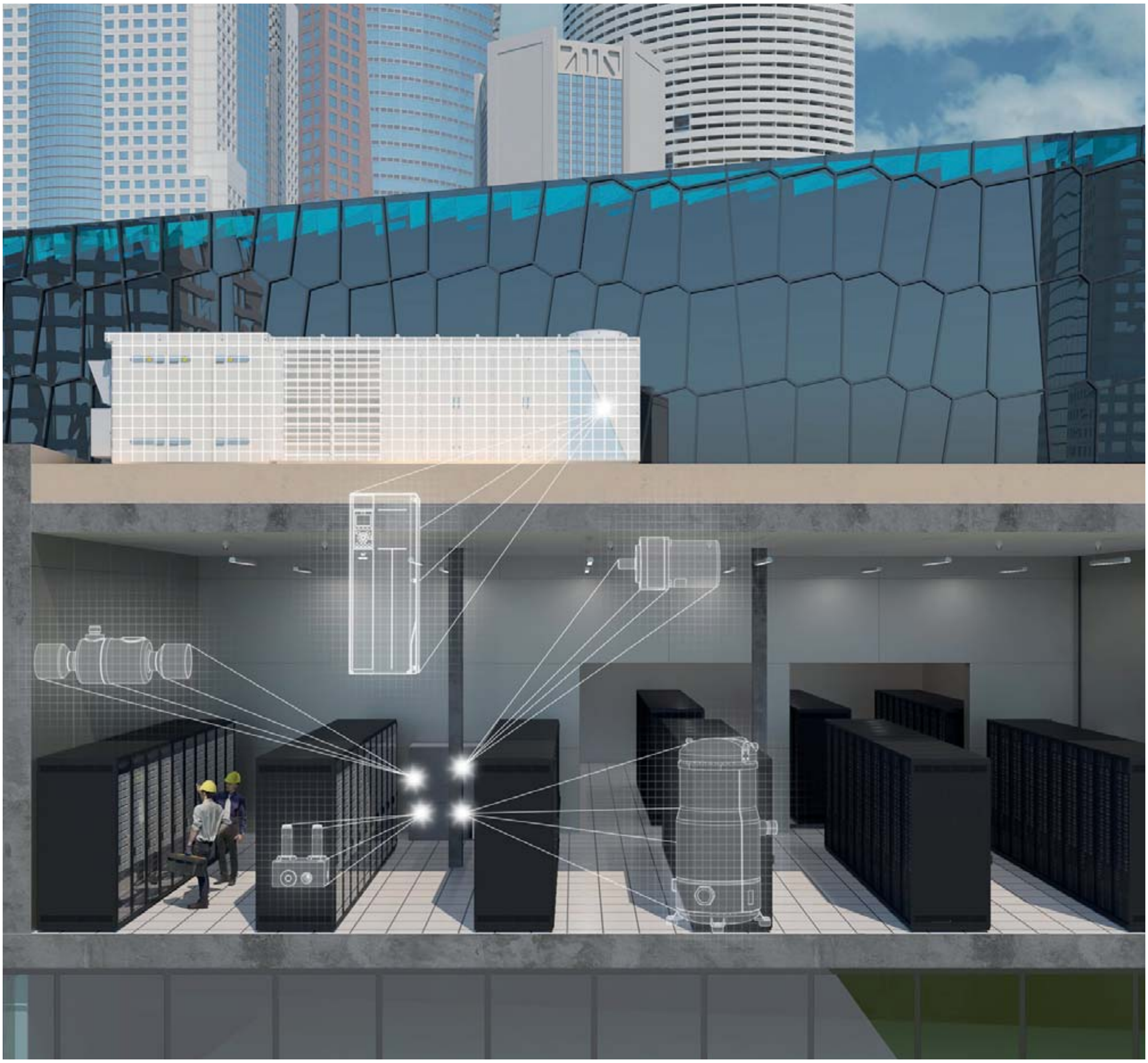
As a global leader in energy-efficient solutions, Danfoss is working with Google to implement sustainable cooling systems for data centres and to design systems that reuse the excess heat produced by data centres. Danfoss Turbocor® compressors provide highly reliable, highly efficient solutions when expertly applied by OEM partners and are being installed by Google to improve the energy efficiency and decarbonize heating and cooling systems in data centers.

Ravichandran Purushothaman, President, Danfoss India Region said, "Danfoss and Google's strategic partnership will accelerate the digital transformation of customer experience. Leveraging latest technological advancements in AI and energy efficiency in data center operations will help Danfoss' customers to achieve common objectives of sustainability, operational excellence, and business performance."

Meanwhile, Danfoss' heat reuse modules will make it possible for Google to capture and reuse heat produced by data centres—providing a renewable energy source to supply heating on-site and to neighboring commercial and residential buildings, communities, and industries that need heat for their processes. Going forward, Danfoss' expertise in decarbonization solutions will be used to an even greater extent to advance data centre sustainability in Europe, North America, and beyond.

Anju Mary Kuruvilla, Director–Industry affairs, Communications, Sustainability and CSR said, "The solution will have the capability to help customers achieve their sustainability and energy transition objectives by providing advanced monitoring and optimization insights into the carbon emissions and energy usage."

The new agreement, announced during the AHR Expo in Chicago, USA, builds on an existing collaboration



between the two companies, which were among the founders of the Net Zero Innovation Hub in Fredericia, Denmark (announced in September 2023), where a number of major players joined forces to accelerate the green transformation of data centres. Danfoss and Google are now taking a step further by entering into a broader partnership.

Jürgen Fischer, President, Danfoss Climate Solutions, said: "At Danfoss, we want to revolutionize how we build and decarbonize data centres together with our customers. When we partner up across industries, like we have done with Google, we accelerate this development towards building better and more sustainable data centres—using technologies available today."

Google Vice President of Data Centre Innovation, JP Clausen, is excited about the collaboration. "This is a great example of a partnership utilizing each other's strengths and using technology to optimize the customer experience, increase productivity and reach sustainability goals. Danfoss is a leader in energy efficiency, and these solutions help support Google's 2030 goal of running our data centres on carbon-free energy 24/7. We're happy to deliver AI innovation through Google Cloud, enabling businesses like Danfoss to operate in new and smarter ways," says JP Clausen.

About Danfoss A/S

Danfoss engineers solutions that increase machine productivity, reduce emissions, lower energy consumption, and enable electrification. Our solutions are used in such areas as refrigeration, air conditioning, heating, power conversion, motor control, industrial machinery, automotive, marine, and off- and on-highway equipment. We also provide solutions for renewable energy, such as solar and wind power, as well as district-energy infrastructure for cities. Our innovative engineering dates back to 1933.

For more information, visit *www.danfoss.com*

About Danfoss India

Danfoss India is an industry leader focused on energy efficient solutions. It serves a wide range of industries that rely on Danfoss products like drives, heating valves, controls and solutions for refrigeration, air conditioning, HVAC, heavy industries, district cooling, hydraulics, fluid conveyance and under floor heating applications. Danfoss engineers technologies that enable the world of tomorrow to do more with less. Danfoss India Region, headquartered at Chennai, focusses on designing and innovate products for both India and outside market.

About Google

Google's mission is to organize the world's information and make it universally accessible and useful. Through products and platforms like Search, Maps, Gmail, Android, Cloud, and YouTube, Google plays a meaningful role in the daily lives of billions of people and has become one of the most widely known companies in the world. Google is a subsidiary of Alphabet Inc. EF

GE RENEWABLE ENERGY TO SUPPLY 81 TURBINES TO CONTINUUM GREEN ENERGY

GE Renewable Energy and Continuum Green Energy Limited have entered into a business agreement whereby GE Renewable Energy will supply, install, and commission 81 units of its 2.7–132 onshore wind turbines to Continuum for its 218.70 megawatt (MW) wind power projects across Tamil Nadu and Madhya Pradesh. The orders have been placed by Continuum subsidiaries—Continuum MP Windfarm Development Private Limited and Dalavaipuram Renewables Private Limited. Last year, GE had supplied turbines for Continuum's 148.5 MW Morjar, Bhuj and 99.9 MW Rajkot wind farms in Gujarat.

The wind farms, which would be managed by Continuum, will provide local businesses and consumers with accessible, affordable, and reliable energy. Continuum is a leading player in offering bespoke green energy supply solutions to the Indian market.

Deepak Maloo, Regional Sales Leader for GE Renewable Energy's Onshore Wind in Asia Pacific said, "We are pleased to extend and deepen our partnership with Continuum in India. This is truly a testament to our strong working relationship and Continuum's continued trust in our technology and capacity to deliver turbines. We look forward to furthering our partnership with Continuum in the future as they continue to build out their renewable energy portfolio in India. Over the last year, we have secured over ~2 GW of orders in India, making us one of the largest wind turbine original equipment manufacturer (OEM) supplier in the country."

Arvind Bansal, Chief Executive Officer (CEO), Continuum Green Energy opined, "We are happy to collaborate with GE in our endeavour to accelerate India's energy transition towards a sustainable and carbon-neutral future. GE is a trusted partner to Continuum. Our common purpose of delivering green energy to power the future of the planet brings together lot of synergies."

GE's 2.7–132 wind turbine has proven to be the technology of choice for many customers in India due to its industry-leading performance at India's low-wind speeds. The project will leverage GE's significant local footprint in India. The product would be designed primarily at GE's Technology Centre in Bengaluru, blades are to be manufactured in GE's plants in Vadodara, while assembling of the parts would be carried out at the GE's multi-modal manufacturing facility in Pune.

GE Renewable Energy is committed to enabling the energy transition by supporting the work of its customers. As part of that responsibility, the business is focused on supplying and maintaining a global fleet of renewable energy assets, helping reduce the cost of renewable energy, ensuring grid resiliency, efficiency, and reliability, and making renewable energy function in a more dispatchable fashion. GE Renewable Energy also supports the energy transition by pursuing a strategy that reflects a commitment to sustainable, circular design.

(*Based upon India's per capita energy consumption, i.e., 1208 kWh, as of 2020)

About GE Renewable Energy

GE Renewable Energy, a part of GE Vernova, combines one of the broadest portfolios in the renewable energy industry to provide end-to-end solutions pertaining to reliable and affordable green power. Combining onshore and offshore wind, blades, hydro, storage, utility-scale solar, and grid solutions as well as hybrid renewables and digital services offerings, GE Renewable Energy has installed more than 400+ gigawatts of clean renewable energy and equipped more than 90% of utilities worldwide with its grid solutions.

For more information, visit *www.ge.com/renewableenergy*

About Continuum Green Energy

Continuum is an India-focused renewable energy platform with 1+ GW of operating and under-construction capacity. Continuum is majority-owned by a global infrastructure fund managed by Morgan Stanley Infrastructure Partners. EF

For more information, visit *www.continuumenergy.in*

RENEWABLE ENERGY AT A GLANCE

Ministry of New & Renewable Energy		
Programme/Scheme wise Cumulative Physical Progress as on March, 2024		
Sector	**FY 2023-24**	
	Achievements (1st April 2023–31st March 2024)	**Cumulative Achievements (as on 31.03.2024)**
I. INSTALLED RE CAPACITY (MW)		
Wind Power	3253.39	45886.51
Solar Power*	15033.26	81813.60
Small Hydro Power	58.95	5003.25
Biomass (Bagasse) Cogeneration	0.00	9433.56
Biomass (non- bagasse) Cogeneration	107.34	921.79
Waste to Power	1.60	249.74
Waste to Energy (off-grid)	30.16	336.06
Total	**18484.70**	**143644.51**

Source: https://mnre.gov.in/the-ministry/physical-progress

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